Simulation and Validation of SPV micro grid comprising 518.2 KWp Distributed Solar Power Plants at Dayalbagh Educational Institute

Ph.D. SYNOPSIS

Submitted by

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1. Introduction

Energy and water are the keys to modern life and provide the basis necessary for sustained economic development rising energy prices, diminishing energy availability and security, and growing environmental concerns are quickly changing the global energy panorama. Industrialized societies have become increasingly dependent on fossil fuels for myriad uses. Modern conveniences, mechanized agriculture, and global population growth have only been made possible through the exploitation of inexpensive fossil fuels. Securing sustainable and future energy supplies is the greatest challenge faced by all societies in this century. [1]

Due to a growing world population and increasing modernization, global energy demand is projected to more than double during the first half of the twenty-first century and to more than triple by the end of the century. Presently, the world's population is nearly 7 billion, and projections are for a global population approaching 10 billion by midcentury. Future energy demands can only be met by introducing an increasing percentage of alternative fuels**.** Incremental improvements in existing energy networks will be inadequate to meet this growing energy demand. Due to dwindling reserves and ever-growing concerns over the impact of burning carbon fuels on global climate change, fossil fuel sources cannot be exploited as in the past. [1]

Finding sufficient supplies of clean and sustainable energy for the future is the global society's most daunting challenge for the twenty-first century. The future will be a mix of energy technologies with renewable sources such as solar, wind, and biomass playing an increasingly important role in the new global energy economy. The key question is: How long it will take for this sustain able energy changeover to occur? And how much environmental, political, and economic damage is acceptable in the meantime? If the twenty-first century sustainable energy challenge is not met quickly, many less-developed countries will suffer major famines and social instability from rising energy prices. Ultimately, the world's economic order is at stake. Approximately one-third of the world's population lives in rural regions without access to the electric grid, and about half of these same people live without access to safe and clean water. Solar energy is unique in that it can easily provide electricity and purified water for these people today with minimal infrastructure requirements by using local energy resources that promote local economic development. [1]

1.1 Micro Grids

"A group of interconnected loads and distributed energy resources (DER) with clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid [and can] connect and disconnect from the grid to enable it to operate in both grid connected or island mode." [2]

Economic, technology and environmental incentives are changing the features of electricity generation and transmission. Centralized power systems are giving way to local scale distributed generations. At present, there is a need to assess the effects of large numbers of distributed generators and short term storage in Micro grid. The use of renewable energy and emission penalty can significantly reduce the total carbon emissions. There is a need to account for various combinations of Micro grid components to evaluate the optimal operating configurations using advanced planning technologies. [3]

Micro grids have been identified as a key component of the smart grid in order to improve system energy efficiency and reliability and to provide the possibility of grid-independence to individual end-user sites. As defined by the Micro grid Exchange Group (MEG), "A micro grid is a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid. A micro grid can connect and disconnect from the grid to enable it to operate in both grid-connected or island-mode." [4]

The long-term goal for the US DOE Office of Electricity Delivery and Energy Reliability (OE) micro grid initiative is: "To develop commercial scale micro grid systems (capacity <10 MW) capable of reducing outage time of required loads by >98% at a cost comparable to non-integrated baseline solutions (uninterrupted power supply [UPS] plus diesel gen set), while reducing emissions by >20% and improving system energy efficiencies by >20%, by 2020." [4]

According to the MEG (Micro grid Exchange Group), the benefits of micro grids include:
1. Enabling grid modernization and integration of multiple smart grid technologies.
2. Enhancing the integration of distributed and renewable energy sources that help to reduce peak load and reduce losses by locating generation near demand.
3. Meeting end-user needs by ensuring energy supply for critical loads, controlling power quality and reliability at the local level, and promoting customer participation through demand-side management and community involvement in electricity supply.
4. Supporting the macro grid by handling sensitive loads and the variability of renewable locally and supplying ancillary services to the bulk power system. [4]

1.2 National Status

India is facing the challenge of massive increase in energy consumption for development while avoiding a catastrophic impact on the environment. With the economy growing at a rate of around eight percent a year, the demand for electricity in India is skyrocketing. In response, village and larger-scale micro-grids are springing up in many areas – giving hope to the estimated 40 million Indians not yet connected to the woefully inadequate national grid. The Indian government is promoting solar-powered micro-grid systems as part of its national redevelopment program, and hopes to use that experience to establish India as a world leader in solar power technology [5]. One recent estimate put the potential market for "off-grid" power networks in India at around $2 billion a year [6].

- *As on August 2012, the installed capacity of Solar Power Plants in India is 1140.61 MW (4.3%), out of 26615.38 MW generated from all renewable energy sources.[5]*
- *Last two years have seen a spurt of growth in Grid Interactive MW size solar electric plants, from 36 MW in 2010-11 to 1030 MW by June 2012, in line with the National Solar Mission to increase the capacity to 1300MWp by 2013[5,7].*
- *The amount of land required for utility-scale solar power plants could pose a strain on India's available land resource. Moreover, India's grid system is considerably under-developed, with major sections of its populace still surviving off-grid.*

- *Therefore, one of the architectures suitable for most of India would be a distributed set of rooftop power generation systems, or local renewable energy grids. Such a system can sustain independently of the Grid, which is suitable for India in view of scarcity and frequent outages of grid, especially in remote areas.*
- *A demonstration project was sanctioned to TERI under the aegis of Asia-Pacific Partnership on Clean Development and Climate (APPCDC) in March, 2009 with the contribution of Rs.87 lakhs from the Ministry of New & Renewable Energy. The project was completed with the technical collaboration of the Solar Energy Centre under the Ministry of New & Renewable Energy in July 2011. The smart mini grid has been deployed at TERI Retreat building in which 3.2 kW wind generator, 10.5 kW solar PV power, 1 kW thin film, 2 kW SPV systems, 100kW biomass gasifier and diesel generator have been integrated to demonstrate optimal evacuation of renewable power[8].*
- ***Dayalbagh Educational Institute is a unique university that has commissioned 518.2kWp Solar PV distributed power plants (7 in number) with a project cost of over Rs. 11 crore, sufficient to fulfill all electric power requirements (including classrooms, laboratories, workshops, computer center, water pumps etc.) of the institute on a clear day. The project was completed in October 2011. This is an ideal test bed for the application of the concept of smart micro grid and for demonstrating how an optimal solar/grid synergy along with energy storage allows for demand-response reliability and cost saving and reducing the carbon footprint [9].***
- *The effectiveness of renewable energy based micro grid was clearly seen during the Northern Grid failure on30th and 31st August 2012. For two consecutive days the whole of Eastern and Northern India came to a standstill. However, thanks to the SPV micro grid, Dayalbagh Educational Institute was not affected by the grid failure. Even during normal days, a power cut of about 2-4 hours is observed in Agra. DEI, through the SPV plants, is coping up very well. [10]*
- *Time varying stochastic loading and changing climatic conditions based renewable power generation calls for judicious solar/grid synergy for optimal economy, efficiency and reliability of the system.*
- *The concept of smart micro grid with integration of close monitoring, analysis, control and communication promises to handle the above mentioned concerns effectively. Not much R&D work is being done in India on renewable energy smart grids.*

1.3 International Status

- *Post Fukushima, all major European countries have decided to phase out nuclear power and replace it with renewables [11] :*
  - *Switzerland – 3000MW to be replaced by 2035*
  - *Germany – 20500MW to be replaced by 2022*
  - *Belgium – 5500MW to be replaced by 2025*
  - *France – 1800MW to be replaced by 2016*
- *As most of these countries have almost exhausted all their Hydro resources, the only viable options left are wind and SPV [11].*

- *In 2010, Illinois Institute of Technology received US$12.6 million to establish IIT Smart Grid Education and Workforce Center. IIT signed a contract with Exelon Energy for about UD$40/MWh for a generation mix that is 75% carbon free with 25% hydro power[12].*
- *Schneider Electric has collaborated with the Innovation Center for Mobility and Social Change (InnoZ) to complete a micro smart grid at the EUREF-Campus in Germany's capital city.The aim of the micro smart grid is to test the possibilities of energy storage with regards to renewable energy sources and electric mobility together. Schneider Electric consolidates its offices in Berlin in one of the newer buildings, number seven, on the campus since summer last year. The micro smart grid is an intelligent network that enables the interaction of various components and allows them to be tested. The components include five wind generators with an output of one kilowatt (kW), two photovoltaic systems on the roof of the building with about 20 kW of peak power each, and another solar system with a peak power of 7.5kW which incorporates a tracking system [13].*
- *According to Pike Research, a Cleantech Market Research firm, the global remote micro grid market will jump from 349 megawatts in 2011 to 1.1 gigawatts by 2017 to meet the rising demand, especially in developing countries, representing total project revenue of over $10.2 billion by that time [6].*

2. Outline of the Proposed Thesis

2.1 Solar Photovoltaic Micro Grid at Dayalbagh Educational Institute

- Last two years have seen a tremendous growth in Solar PV and Solar thermal installations in India, thanks to National Solar Mission of increasing the installed capacity to 1000 MWp by 2013 and 20,000 MWp by 2020. The challenge now is to utilize the installed capacity effectively to make the development sustainable.
- **Smart Micro Grid Technology** that combines centralized monitoring, communications and control of every aspect of a micro grid to optimally use renewable energy along with the utility electric supply is proposed to be the solution for a sustainable development in this area. This is a recent area and hectic activities have started across the globe in this direction.
- It is therefore important that expertise may be developed in Smart Micro grid technologies in India for optimal utilization of solar energy in the face of dynamic electrical loads and vagaries of weather conditions in India.
- The **Dayalbagh Education Institute** (Deemed University) is one of the premiere universities of India. The Institute has introduced a scheme of innovative and comprehensive education at university and non-university general and technical education levels which aims at excellence but not at the cost of the relevance, which inculcates dignity of labour, encourages initiative and creative work, which is multi-disciplinary, which prepares men for the increasingly techno-oriented society of tomorrow without uprooting them from their agricultural moorings, which will generate in the alumni the basic values of humanism, secularism and democracy by exposing them to the principles of all the major religions of the world and to their own cultural heritage, thus developing in them an integrated personality

of well-adjusted men whose world has not been broken into fragments by narrow domestic walls.

- In order to attain the lofty vision through sustainable developmental activities in agreement with the concept of Eco-Village, Dayalbagh Educational Institute has taken initiatives in harnessing the non-conventional and renewable energy like Solar thermal and Solar PV with projects costing over 12 crores.. The institute has Solar Thermal Cooking systems in all the hostels. The whole university is powered by Distributed roof-top Solar PV power Plants aggregating to a total of 518.2kWp. The institute is committed toward the cause of protection of environment and self-sufficiency in the area of renewable energy. Development of Dayalbagh area on the lines of eco-city concept is an important milestone in the institute's vision for next decade.

- There are seven solar electric power plants at Dayalbagh Educational Institute. The locations and capacities of the power plants are given in the following table (*Fig 1: a satellite view of six of the seven plants installed and their coverage*).

Sl. No.	Site	SPV Capacity
1	Faculty of Engineering	147.8 kWp
2	Faculty of Science	148.32 kWp
3	Faculty of Arts	40.8 kWp
4	Faculty of Education	40.8 kWp
5	Faculty of Social Science	40.8 kWp
6	USIC Complex	94.68 kWp
7	Boys Hostel	5 kWp

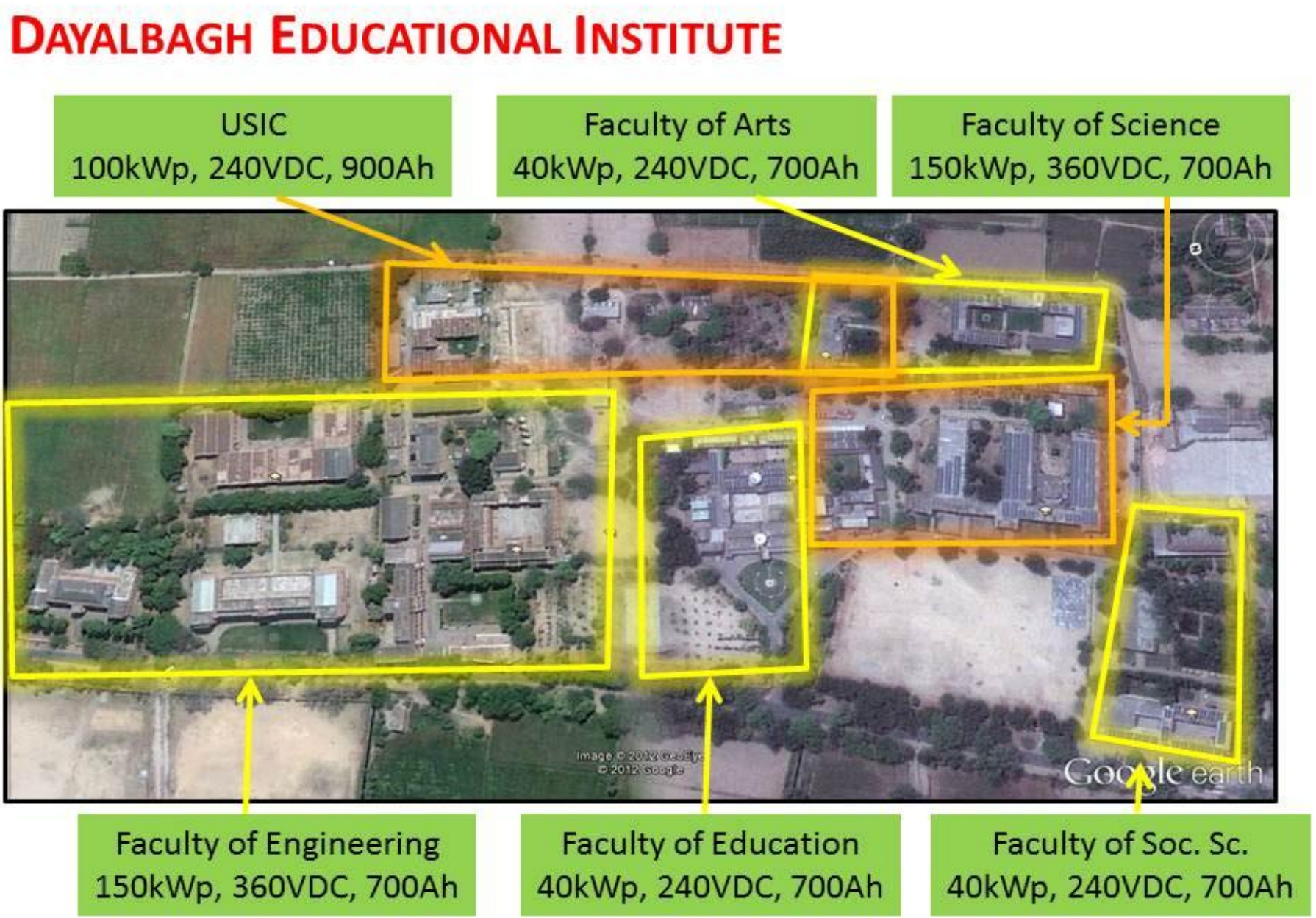

Fig 1 : Satellite view of the institute showing six of the seven existing plants and their coverage

All the power plants are Hybrid PV Power Systems, primarily intended to power independent localized loads as well as to export excess PV power to grid. The three phase DSP based, Grid Support Conditioners (GSC) (*Fig 2*) are designed to operate as a multi-function power conditioning unit combining the functionality of a grid interface solar inverter with a true on line single conversion UPS. The GSC system allows the option of combining renewable energy sources on priority with the functionality of an industrial UPS system. Based on the Solar power available, connected load and battery state of charge, the unit configures itself as either a charger or inverter and can start an optional back up Diesel Generator, if the battery reserve cannot be maintained by the Solar power and there is loss of grid power. In charging mode the system maintains the battery voltage at a user specified value and charges the battery in accordance with standard procedures, thus maximizing the life of the battery bank. The DSP based GSC provides output voltage conditioning when operating in a grid interactive mode and has the ability to export excess Solar power to the grid.

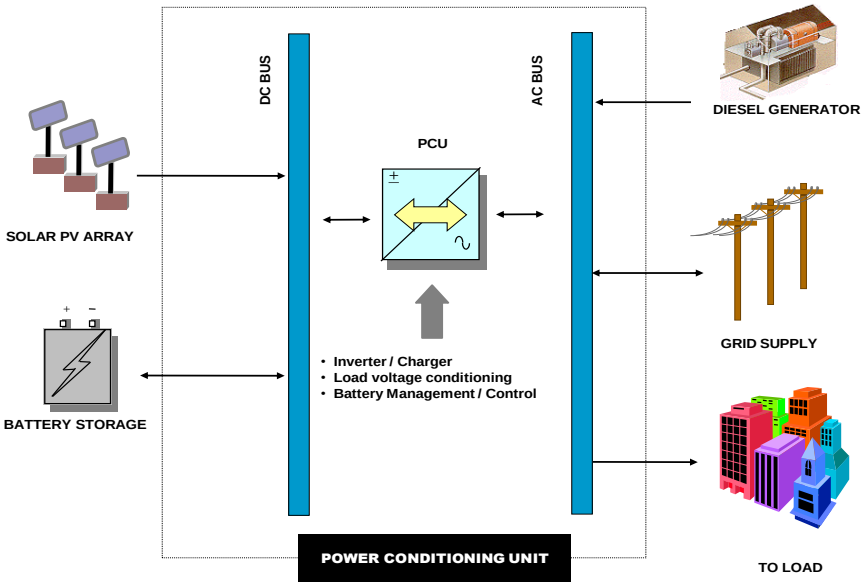

Fig 2: Grid Support Conditioner System

- The PV Panels are mounted on fixed stands facing south and inclined at an angle of 30^0 from horizontal.
- Load circuits are connected through manual changeover switches in the PCU rooms of respective plants.

2.2 SYSTEM FEATURES

- Maximum power point tracking (MPPT) of PV energy.
- Full automatic operation with no break to the supply during transitions from inverter and grid to Inverter operation.
- Output voltage conditioning when operating in grid interactive mode to ensure stable and reliable supply to the site loads.
- Ability to export excess Solar power to the grid.
- Diesel Generator when called up is optimally loaded giving high fuel efficiency and lower overall maintenance, if connected.
- Solar power is fed directly to the site load via the inverter as much as possible to minimize losses due to battery bank.

- Capable of being integrated with renewable/distributed generation sources on both the AC and DC bus.
- Local LCD (liquid crystal display) and keypad for system control, monitoring instantaneous system data, event logs, data logs and changing set points.
- Time and date data logs and event logs available for importation into a spread sheet for analysis via a local RS232 connection.
- Remote control and monitoring option using standard or GSM modem available. Communication based on LAN/WAN protocol is also available.

Faculty of Science

Solar Charge Regulator

- MPPT based pulse charging hence better charging efficiency
- IGBT devices employed
- Battery temperature compensation provided
- Protection against battery High & Low
- Protection against lightening & surges
- Monitoring /indication of battery state of charge, Ah generated
- Provision for float voltage operation
- Trickle charging facility

Inverter

- PWM control algorithm
- IGBT based
- Conversion efficiency ≥ 92%, with a minimal no load loss
- Utility grade sine-wave, 230VAC (nom), 1 phase, 50 Hz
- Total harmonic distortion < 4 %
- Protection against
  - Input over-voltage and under-voltage
  - Over temperature
  - Over Load- 120% full load for 10 minutes and 150% FOR 10 Seconds
  - Voltage regulation ≤ 2%
  - The system can work at temperatures ranging from 0 to 500C for PCU and -400C to +85 0C for solar PV modules

Metering and Indicators

40x4 LCD panel with membrane keypad displaying the following:

- Grid and inverter per phase kW, voltage, pf, freq.
- Grid & Inverter on line status
- Battery voltage, battery current, battery temperature
- Solar charge current and ambient temperature
- Individual power stage heat sink and cabinet temperature

Faculty of Education

- Wind charge current (optional)
- Fuel flow (x2), fuel level (optional)
- Solar radiation and Wind speed (Optional)
- Inverter, gen set and site kWh summation gen set run hours
- System set points, event logs and data logs
- Inverter ON Line and Grid ON line
- System Fault

Protection features

- Inverter continuous overload protection
- Inverter peak current(short circuit) protection
- Heat sink over temperature protection
- Over/under voltage AC voltage protection
- Over/under frequency protection
- Over/under battery voltage protection

Data Logging Features

- Adjustable logging repetition from 1 sec-60 second
- Storage capacity of upto 100 days with 5 second logs
- Time and date stamped log entries
- Time and date annotated fault log, holding the fault description and operating statistics
- View and change system set point configurations remotely
- Bulk log download for data importation into a spread sheet where applicable

System summations

- Site kWh
- Inverter input and output kWh
- Grid and Genset kWh
- Genset run hours
- Battery input & output kWh
- Solar kWh

System Parameters

- Grid kW, voltage, pf, frequency
- Inverter kW, voltage, pf, frequency
- Battery current
- Battery voltage
- Battery temperature
- Ambient temperature
- Solar charge current
- Heatsink & cabinet temperatures
- Solar radiation (with external pyranometer)

Boys Hostel

3. The Road Ahead

Having installed the sufficient capacity for the institute, the challenge now is to come up with an efficient, reliable and economically viable system in the presence of dynamic loading conditions, generation sources which depend on the weather and an unreliable utility supply. The main problems which prevent the desired operation include the following:

- Lack of coordination between various solar plants
- Overloading of inverters
- Inefficient operation of inverters
- Fault diagnosis of inverters
- Unutilized solar power in the absence of grid
- Loss of battery gravity due to frequent discharge
- String Monitoring and fault diagnosis of SPV panels
- **Absence of a good simulation model of the micro grid which would facilitate analysis and optimization of the system under different loading conditions and can also pave way for an optimized system operation.**

The aforementioned problems can be solved with integrated operation, monitoring, communication, control and fault diagnosis of all the Solar Electric Power Plants, through a central control station. This would lead towards the philosophy of Smart Micro Grid. An important part of a Smart Micro Grid is a Decision Support System to assist the operator for optimal efficiency, economy and reliability in system operation. This makes a good simulation model of the micro grid very essential.

The main focus of the proposed thesis is modeling and simulation of the micro grid comprising of seven distributed SPV power plants interconnected through a distribution network at Dayalbagh Educational Institute.

4. Literature Survey

The main components of a solar photovoltaic power plant include SPV modules, Maximum Power Point Tracking (MPPT) charge controller, Solar Inverter and Batteries. The literature survey is therefore summarized accordingly in different categories as below:

4.1 Simulation of Solar Photovoltaic Panels

A solar panel is a device that converts light into electricity. Solar electric equipment like inverters or maximum power point trackers must be used to harness solar power. Such equipment needs to be rigorously tested for power quality, protection, safety and other issues. Testing in a natural environment using solar panels presents difficulties in terms of repeatability as well as achieving full range of environmental parameters such as solar radiation and temperature which strongly impact the performance of photovoltaic systems. The paper [14] work presents a programmable solar photovoltaic simulator which can eliminate the need for using actual solar panels for testing and development purposes.

From 1986 onward, New England Electric has carried out and supported a wide range of research, development and demonstration projects related to the use of solar photovoltaic (PV) energy. The paper [15] describes each project and summarizes performance to date. Several projects embody the concepts of distributed generation (DG) and demand-side management (DSM) as well as utilization of renewable energy. The design of an autonomous SPV based

system is presented in [16]. The result shows that PV system would be suitable to supply electricity to cover the load requirement without using energy from the grid. Reference [17] presents a C++ computer program to implement the selected design procedures and calculates size ratings of the various components of the PV system. The program accepts the load demand details from the client as input data together with the solar insolation.

A study of the effects of PV string size on annual system energy production and yield has been conducted for several locations in Europe with significantly different weather as well as for locations with extreme climatic conditions such as high altitude and desert areas. [18]

A test set-up for the study of Arc faults in SPV modules is presented in [19]. The analysis of the measured signals in time and frequency domain presented show that the Parallel arcing involves significant changes in the current at the primary side of the converter and is therefore easily detectable. A parallel inverter configuration for residential photovoltaic (PV) systems consisting of two inverters of different sizes is proposed in the paper [20]. The paper [21] presents a comprehensive testing, validation and installation plan for a new technology which utilizes PV solar farm as a STATCOM both during night time and daytime. The paper [22] presents a novel technology of utilizing Photovoltaic (PV) Solar Farms in the night time. New controls are developed for the solar farm inverters to operate as STATCOM – a Flexible AC Transmission System (FACTS) Controller, using the entire inverter capacity in the night for accomplishing various power system objectives, such as voltage regulation, improvement of power transfer capacity, load compensation, etc. An auto-interference controller for SPV-wind system is presented in [23]. To capture the wind and the light in the greatest degree, the method of nonlinear transform of aerodynamic force is used, as well as the theory of brushless double-fed wind generator and the principle of extremism control on solar inverter are adopted. The hierarchical fuzzy controller algorithm is presented for controlling the loading and unloading of wind generators, solar cells and the grid, considering the multi-input and multi-output of the distributed hybrid power system. Paper [24] provides a bottom-up approach for modelling hourly electricity output based on meteorological data and technical specifications for different reference plants. Electricity output for wind power is based on hourly data on wind speed, ambient temperature and atmospheric pressure and calculated considering different turbine power curves and hub heights. Paper [25] presents an integrated design method of PV stations using Dig SILENT Power Factory and Mat lab/Simulink. The method enables a fast and effective access to complex PV system modelling and analysis. A real time optimization of parameters for the current control strategy for a 3-phase photovoltaic grid-connected Voltage Source Inverter (VSI) system is reported in [26]. The proposed controller scheme is implemented based on a synchronous reference frame; the Phase-Locked Loop (PLL) is used as grid phase detector. Particle Swarm Optimization (PSO) algorithm is used to implement the real time self-tuning method for the current control parameters. The results show that the proposed strategy provides an excellent dynamic response within real time optimization.

4.2 Simulation of Maximum Power Point Tracking (MPPT) Charge Controllers

DC power from solar panel is boosted through an MPPT controller and fed to an inverter which gives ac output. One such scheme is proposed in the paper [27]. In this work, depending on solar radiation and temperature, the MPPT controller gives optimized duty cycle. Neural network and fuzzy logic are two MPPT controllers, simulated to give optimum duty cycle. These MPPT controllers are compared based on the power obtained from the boost converter. Simulation results are also presented.

The paper [28] presents a PSCAD/EMTDC model of PV solar panels, the grid connected three phase voltage sourced inverter (VSI) and its controller system. The VSI control is implemented with current control loops. A maximum power point tracking (MPPT) algorithm is implemented to get the maximum output power for any given solar irradiation and temperature. The paper [29] focuses on the impact of large solar plants on power systems due to rapid variation in power injection caused by various factors such as the intermittency of solar radiation, changes in temperature and tripping out of power electronic based converters connected to the system.

The paper [30] presents, a strategy for tracking the maximum power point (MMPT) for several solar insolation levels. The paper [31] presents, a voltage based maximum power point tracking scheme developed for the inverters. Mathematical models are formulated and then a tracking algorithm is evolved. The paper [32] concerns the combination of a photovoltaic (PV) grid-feeding inverter with a motor control unit for two-axis solar trackers. The paper [33] presents, a maximum power point tracking algorithm that optimizes solar array performance and adapts to rapidly varying irradiance conditions. In particular, a novel extremism seeking (ES) controller that utilizes the natural inverter ripple is designed and tested on a simulated solar array with a grid-tied inverter. The new algorithm is benchmarked against the perturb and observe (PO) method using high-variance irradiance data gathered on a rooftop array experiment in Princeton, NJ. The paper [34] proposes Sinusoidal Pulse- Width Modulation (SPWM) technique in single-phase PWM inverter for PV generation system. A novel stand-alone PV generation system based on a nonlinear maximum power point tracking method and SPWM control scheme for single-phase voltage source PWM inverter is built in Matlab/Simulink software. Simulation results show the feasibility and effectiveness of the proposed method. The paper [35] focuses on the impact of large solar plants on power systems due to rapid variation in power injection caused by various factors such as the intermittency of solar radiation, changes in temperature and tripping out of power electronic based converters connected to the system. The paper [36] presents, the design procedure and performance of a solar-PV (photovoltaic) energy generating system using an isolated zeta converter for meeting an energy demand of rural households.

The paper [37] presents, control algorithm design for a three-phase single-stage grid-connected PV inverter to achieve either maximum power point tracking (MPPT) or a certain amount of real power injection, as well as the voltage/var control. The switching between MPPT control mode and a certain amount of real power control mode is automatic and seamless.

The paper [38] proposes techniques of maximum power point tracking (MPPT) implemented with finite step model predictive control (FSMPC) for the application of Z-source inverter. Incremental conductance MPPT algorithm and FSMPC model is developed to control the output current of the grid-tied Z-source inverter in order to extract maximum solar power from the panel and then directly injecting the power into grid. A DC to AC Inverter and power switching system is presented in the paper [39]. The paper [40] presents the theoretical analysis, design and simulation of a single phase single stage boost dc-ac converter powered from PV array. The main attribute of the boost inverter topology is the fact that it generates an ac output voltage larger than the dc input one, depending on the instantaneous duty cycle. The paper [41] presents laboratory implementation of a photovoltaic artificial neural network (ANN) based maximum power tracking controller. The control purpose is to track the maximum available solar power in a photovoltaic array interfaced to an electric utility grid via a line commutated inverter. Due to its ability to handle nonlinear functions regardless of the derivative information, Evolutionary Programming (EP) is envisaged to be very effective for Maximum Power Point Tracking (MPPT) of Photovoltaic cell (PV). The paper [42] proposes a critical evaluation of MPPT algorithm of PV model using EP. The paper [43] presents a simulation model

of the electric part of a grid connected photovoltaic generation system. The model contains a detailed representation of the main components of the system that are the solar array, and the grid side inverter multilevel inverter Neutral Point Clamped (NPC) VSI.
The paper [44] presents, perturbation and observation method to implement Maximum Power Point Tracking (MPPT) for solar cells. Owing to the existence of converters, photovoltaic system is a hybrid system contains continuous dynamic and discrete dynamic. Traditionally, the power electronic converter is difficult to model. The paper [45] presents, a new control algorithm of MPPT (Maximum Power Point Tracking) is proposed. The proposed algorithm takes the interaction between solar arrays, photovoltaic inverter, MPPT control, dc side dynamic model of solar arrays and the light intensity of the solar arrays into consideration.

The paper [46] proposes a high performance, single-stage inverter topology for grid connected PV systems. The proposed configuration can not only boost the usually low photovoltaic (PV) array voltage, but can also convert the solar dc power into high quality ac power for feeding into the grid, while tracking the maximum power from the PV array.

The paper [47] presents Laboratory implementation of a photovoltaic artificial neural network (ANN) based maximum power tracking controller. The paper [48] presents, integration of PV module and STATCOM. And a sample system is simulated in MATALB software to verify the advantages of proposed integrated system. The paper [49] reports on the modelling and simulation of a stand-alone photovoltaic (PV) plant with maximum power point tracking (MPPT) feature and dedicated battery storage. The proposed model is used to determine the voltage, current and power at the maximum power point and then investigate the quality of voltage available at load terminals for different operating scenarios.

4.3 Simulation of Inverters

In paper [50] a reliability study of the entire system (i.e. the solar panels and the inverter) shows that the voltage generated by the solar panel matrix has to be low (< 100 V). This is realized by means of an appropriate feedback system. Paper [51] describes solutions to unbalance problem of the input DC voltages of the five-level neutral point clamping (NPC) voltage source inverter (VSI) using proportional integrator regulator (PI) and fuzzy logic controller (FLC). In the paper [52], starting from the utilization of solar energy, solar inverter status and the basic control method are analyzed. The practical significance and application prospects of the digital power conversion technology and network control are discussed.

The objective of the paper [53] is to propose a novel multilevel inverter using hybrid Photo Voltaic (PV)/wind power system in order to simplify the power system and reduce harmonics and the cost effect. The inverter in a photovoltaic (solar) power system has a critical influence on the efficiency of the overall system [54]. In the paper [55] a hybrid PWM approach has been developed to reduce the switching power losses of the inverter connecting the DC/DC converter to the grid.

The paper [56] presents analysis of a grid connected MLC as an inverter having variable dc sources(which can be the output of wind farms, solar panels etc.). In the paper [57], the design of a vector control including a repetitive controller is outlined. The paper [58] proposes a three-phase three-wire (3+3W) half-bridge single-stage grid-connected PV power inverter. The inverter system can not only transfer solar power into ac power to supply loads or/and to feed utility but eliminates current harmonics and improves power factor.
Analysis and practical implementation of the regular (symmetric, asymmetric) sampled three-phase PWM inverter waveform has been presented in the paper [59], which was digitally

implemented on an Xilinx field programmable gate array FPGA and the essential considerations involved in the feasibility of using a Xilinx XCNOSE software-based to generate PWM.

Based on DSP TMS320F2812, a 10 kW single-phase grid-connected inverter has been built in the paper [60]. DC-DC Boost chopper structure circuit and full bridge inverter circuit are used in the system, with the functions of Maximum Power Point Tracking and anti-islanding effects and a robust digital predictive current controller and etc. The paper [61] proposes a two-stage structure solar inverter topology with maximum power point tracking capability. The control of the solar inverter is digitally implemented using Free scale DSP56F8346. In the paper [62], a three-phase grid-connected inverter has been implemented using DSP-TMS320LF2407A microprocessor. The current controller strategy, namely hysteresis current control, has been employed as an inverter control strategy. Paper [63] has analysed the behaviour of a renewable source of energy by means of analysis of its performance. It has a system of data acquisition to measure variables and to generate data base with these results. The obtained data are analysed by means of data mining technique based on an Evolutionary algorithm. In the study of the paper [64], a grid interactive inverter which is capable of importing electrical energy, generated from renewable energy sources such as wind, solar and fuel cells, to the grid line is designed and simulated with MATLAB/Simulink. The paper [65] presents a Rule based controller, based on fuzzy set theory to control the output power of a PWM inverter in Photo- Voltaic Energy conversion interface scheme. The objective is to track and extract maximum available solar power from the PV array under varying solar irradiation levels. The paper [66] presents the advantage of wind-solar complementary power supply system from the complementarities of time and region. It describes the development of wind-solar complementary single-phase sine wave power inverter and presents its hardware structure, operation principle, and intelligent control method to design for charging and discharging. The paper [67] focuses on the key technical issues and design optimization of large solar power plants. The objective of the paper [68] is to design and analyze a mini solar grid system consisting of PV panels, charge controller, battery and inverter to serve a remote locality. The papers [69-70] presents, Power Electronics Equipment applying superior characteristics Silicon Carbide (SiC) power semiconductors have been researching and developing. In the paper [71] a microcontroller based grid tied solar inverter (GTSI) has been designed and developed. The paper [72] classifies the kW and above range power rating GCTI (grid connected transformer less PV inverter) topologies based on their leakage current attributes and investigates and/illustrates their leakage current characteristics by making use of detailed microscopic waveforms of a representative topology of each class. The cause and quantity of leakage current for each class are identified, not only providing a good understanding, but also aiding the performance comparison and inverter design. The paper [73] presents, a multilevel (5-level) inverter which is used to make total harmonic reduction. The DC/AC inverter is capable of bidirectional power transfer. The LC filter is used in series with the multilevel inverter for filtering the harmonics. The fuzzy controller is implemented in closed loop with the multilevel inverter for the better results. The simulation results are shown in the paper [73]. Using fuzzy logic controller in closed loop with the multilevel inverter, the harmonics is reduced to low value.

The boost inverter presents an interesting topology for solar photovoltaic (PV) applications as a single stage that provides regulated, boosted, and inverted output voltage from a nonlinear dc input. While the boost inverter has been previously addressed from design, implementation, and control perspectives, the paper [74] analyzes its fault modes, failures, and reliability. The inverter is first experimentally tested to validate a simulation model used in the reliability analysis. In the paper [75] a simulation model for the 10kW PV-STATCOM is developed in PSCAD software. The paper presents the steady state and transient performance of the PVSTATCOM controller for voltage regulation and power factor control both during night time and daytime.

The paper [76] proposed a two-switch dual-buck grid-connected inverter with hysteresis current control.

A multi-input multi-output high frequency ac link inverter is proposed as the power electronics interface for photovoltaic (PV) with a built in battery energy storage system (BESS),is described in the paper [77]. In this inverter, a single stage power conversion unit fulfils all the systems requirements i.e. inverting dc voltage to proper ac, stepping up or down the input voltage, maximum power point tracking (MPPT), generating low harmonic ac current with unity power factor at the output and input/output isolation. The paper [77] also examines the possibility of extending this topology to multi-input/multi-output partial resonant converters. Due to the intermittent nature of solar energy, an energy storage system is usually added to the PV system to deliver the reliable power and to draw the maximum power from the PV arrays. Therefore, multi input multi output systems are common in PV systems. In the paper [78] a photovoltaic (PV) 3-phase inverter system is simulated jointly with its control in PSIM software. The main objective of the paper [79] is to develop a power conditioning system, which can be used to extract the variable solar DC power from sun and convert it into AC power to feed a 3- phase AC load effectively. The paper [80] proposes the modified space vector pulse width modulation for the modified Z-source inverter or T-source inverter. The paper [81] discusses potential impacts and benefits of large-scale and micro-scale PV-DG based on conventional power factor control and Generator Emulator Control (GEC) for PV inverters. The purpose of the paper [82] is to model and simulate a three phase inverter that is able to perform well in the presence of balanced or unbalanced loads, and is also able to restrict the fault currents effectively without significant distortions of voltage and current waveforms. To reduce stress on semiconductor devices and harmonic distortion of current waveform, multilevel topology based solar inverters are suggested in literature of the paper [83]. The aim of the paper [84] is to model and simulate a boost inverter and its control method for implementing DC to AC power conversion method. The photovoltaic based load connected system depends up on the number of components and stages involved in the power conversion. Solar integrated current-fed quasi-Z-source inverter (qZSI) has been proposed to overcome the limitations of current-source inverter (CSI) and current fed Z (impedance) source inverter (ZSI), presents in the paper [85].

The paper [86] contributes the digital simulation of renewable energy source controlled EZ-Source inverter system. Input to the Embedded EZ-Source inverter is obtained from solar cell the ripple in the output voltage of solar cell is filtered using Z-jilter.

The paper [87] presents the design of a unique inverter with D-STATCOM capability for small to mid-sized (10kW-20kW) permanent magnet wind installations. The proposed inverter can actively regulate VARs on individual feeder lines at a programmable output while providing the variable output power of the renewable energy source. A power loss model which is a function of the input/output voltage and the output power is proposed in the paper [88] to optimize the efficiency of the interleaved micro-inverter at various input/output conditions. Micro-inverters convert direct current (DC) from a single solar panel to alternating current (AC). The paper [89] presents, structure design and control system of 3KW wind and solar hybrid power systems for 3G base station. The system merges into 3G base stations to save power in order to fully ensure that base stations can supply power normally in any case.

4.4 Simulation of Batteries

For solar power to provide continuous capabilities a method of energy storage is required. This is usually provided by large lead acid batteries that are charged by the panels during sunny times and then discharged at night or bad weather. The most common setup is a lower pack voltage

with at most 48V and high capacity batteries in the thousands of amp hours. There are many advantages of having a higher backup battery voltage. While this can be accomplished with traditional lead acid batteries, the number of batteries required can be cost prohibitive. An alternative solution is inexpensive second life NiMH batteries from end of life hybrid vehicles. While these batteries have come out of vehicles that are no longer rated for traction applications, they still have enough useful life for stationary storage operation. In addition they are sealed and maintenance free making them attractive for backup storage. [90]

The parallel operation of conventional DC-to-DC converters with voltage source characteristics mostly used requires special control mechanism to ensure correct power distribution. The solution proposed in the paper [91] is capable to improve the parallel operation of power stages in conventional converters with modern current sharing techniques. Paper [92] identifies the impacts of high penetration of storage and solar PV by evaluating different case scenarios on a small distribution network in Rockhampton, Queensland, Australia.

It is clear from the literature survey that most of the effort is based on standard mathematical models / MATLAB SIMULINK models available for typical system components. Modelling and simulation of an existing physical system and its validation has not been done so far to the best of our knowledge. Any analysis or optimization study is meaningful only when the results obtained on simulation models can be physically realized on the system. Therefore, a need exists for developing accurate mathematical models of the existing solar photovoltaic micro grid of Dayalbagh Educational Institute and their validation from the practical data.

5. Proposed Work

As is true with any practical system modelling, the conventional mathematical models in their current form may not exist/suffice for all the components and their integration. It is therefore proposed that the thesis would focus on the following problems

- Modelling, simulation and validation of Solar Photovoltaic Panels, strings of SPV panels and combination of strings resulting in a complete power plants.
- Modelling, simulation and validation of Solar Maximum Power Point Tracking Charge Controller.
- Modelling, simulation and validation of practical Solar Inverters existing in the institute.
- Modelling, simulation and validation of the Low Maintenance Lead Acid batteries existing in the institute.
- Modelling and simulation of the complete solar photovoltaic power system by integrating the aforementioned sub-system models.

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